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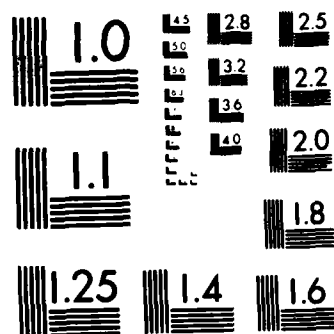UNCLASSIFIED   ARO-18493.14-PH DAAG29-82-K-0018          F/G 20/6      NL

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**19. KEY WORDS** *(Continue on reverse side if necessary and identify by block number)*

Surface polaritons, surface roughness, optics, Fresnel relations, end-fire coupling, grating, diffraction, second harmonic generation, nonlinear optics, scattering, dielectrics

**20. ABSTRACT** *(Continue on reverse side if necessary and identify by block number)*

A research program is proposed for theoretical studies of the propagation and interaction of surface waves. Two types of surface waves will be investigated: surface acoustic waves and surface electromagnetic waves (surface polaritons). The former have important applications in devices such as signal processors and the latter in integrated optics. For both types of surface

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## 20. Abstract (continued)

waves theoretical investigations will be made of the reflection and transmission of surface waves at a planar boundary between two material media. The results will give important information concerning the efficiency with which surface waves pass from one medium to another. Additional studies will be made of the reflection and transmission of surface waves at a step discontinuity both for the situation where the step material is the same as the substrate and where it is different. Another variation of this theme concerns the propagation of surface waves along a periodic structure in which two different materials alternate. For the case of surface polaritons theoretical studies will also be made of their nonlinear interactions. A variety of structure and material arrangements will be investigated in order to achieve phase-matched conditions for second harmonic generation and nonlinear mixing.

THEORETICAL INVESTIGATIONS OF THE PROPAGATION
AND INTERACTIONS OF SURFACE WAVES

Alexei A. Maradudin

February 22, 1985

U. S. ARMY RESEARCH OFFICE

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Department of Physics
University of California
Irvine, California 92717

Thirteen papers were published with support from ARO Grant No. DAAG-29-82-K-0018, during the period of the grant, November 16, 1981 to November 15, 1984. A complete listing of these papers is attached. It is gratifying to note that these papers were published in the leading journals devoted to the subject matter of the grant, viz. Applied Physics Letters, Optics Letters, the Journal of the Optical Society of America, Applied Optics, as well as such physics journals as Physical Review B, Solid State Communications, and Surface Science.

In what follows we describe some of the principal results of the research reported in these papers.

We have shown (Ref. 4) that it is possible to excite surface polaritons (surface electromagnetic waves) at a metal-dielectric interface very efficiently ($\sim$ 90% generation efficiency) by end-fire coupling, in which a p-polarized volume electromagnetic wave is incident on the end face of a metal-dielectric system that is normal to the metal-dielectric interface. We found that this approach gives rise to broad band coupling that is surprisingly insensitive to alignment conditions. This method of coupling should find applications in the conversion of sunlight into electrical energy by means of tunnel-junction plasmons, and for the excitation of long-range surface plasmons for nonlinear optics.

The long-range surface plasmons or polaritons mentioned in the preceding paragraph are surface electromagnetic waves that propagate in a thin metal film that is bounded symmetrically by dielectric media. It has been shown theoretically and experimentally that when the film thickness is of the order of 500Å the mean free path of these surface waves (associated with the imaginary part of the dielectric constant of the metal) can be increased by nearly two orders of magnitude in comparison with its value for a semi-infinite metallic medium. The question had been raised as to whether the roughness of the two metal-dielectric interfaces could decrease these long mean free paths significantly. In Ref. 2 it was shown that this is not the case: moderate degrees of surface roughness decrease the mean free path of the long-range surface polaritons by only a few per cent.

In a second study (Ref. 8) of the interaction of a surface polariton with a transverse discontinuity, we have investigated the refraction of a p-polarized surface polariton propagating along the interface between a metal and a dielectric medium and crossing a boundary into a second dielectric medium. This is a fundamental problem in the optics of surface polaritons, and its solution yields the surface analogs of the Fresnel relations for volume electromagnetic waves. It was found that the specific properties of a surface polariton, such as its exponential localization to a surface, and the fact that it has a component parallel to its direction of propagation, lead to a greater variety of effects than is found in the interaction of a volume electromagnetic wave with an interface. Conversion of the

incident energy into both s- and p-polarized bulk waves occurs, and this leads to a multiplicity of critical angles.

It is believed that the resonant excitation of surface polaritons by light incident on a rough surface is responsible for the major part of the enhancement of various optical pheno- mena associated with metal surfaces. One of these is the surface enhanced Raman scattering from molecules adsorbed on a metal surface. To examine the validity of this belief a calculation of the diffraction of light from a bigrating (a grating that is periodic in two noncollinear directions) was carried out (Ref. 7). The enhancement of the square of the total electric field (relative to the square of the electric field of the incident wave) due to the resonant excitation of surface polaritons made possible by the corrugated surface, was calculated in the vicinity of the surface. Although such calculations have been carried out for classical gratings (gratings that are periodic in only one dimension), this is the first such calculation for a bigrating, which more closely represents a randomly rough surface than does a classical grating. The largest enhancement found for the square of the electric field was by a factor of about 300. If this is squared, to obtain the enhancement in the fourth power of the electric field, which is what is relevant for Raman scattering, an enhancement of $0.9 \times 10^5$ is obtained. This is within 1-2 orders of magnitude of the measured surface enhance- ment ($10^5$ - $10^6$) of the Raman effect. Chemical effects are presumably responsible for the difference.

In a related study the enhancement of the intensity of second harmonic generation of light in reflection from a metal grating was calculated (Ref. 13). The enhancement again is due to the resonant excitation of surface polaritons at the frequency of the incident light, an excitation that is made possible by the corrugated surface. Through the nonlinear dielectric suscepti- bility of the metal, the enhanced first harmonic field in the metal gives rise to an enhanced, reflected second harmonic field, whose intensity is of the order of $10^5$ times larger than it is in the case of second harmonic generation in reflection from a planar metal surface. This is of the same order of magnitude as the enhancements measured experimentally.

1.  Surface Polariton Reflection and Radiation at End Faces, R. F. Wallis, A. A. Maradudin, G. I. Stegeman, Appl. Phys. Lett. 42, 764-766 (1983).
2.  Effect of Surface Roughness on the Attenuation of Surface Polaritons on Metal Films, Gil A. Farias and A. A. Maradudin, Phys. Rev. B27, 7093-7106 (1983).
3.  Iterative Solutions for Electromagnetic Scattering by Gratings, A. A. Maradudin, J. Opt. Soc. Am. 73, 759-764 (1983).
4.  Excitation of Surface Polaritons by End-Fire Coupling, G. I. Stegeman, R. F. Wallis, and A. A. Maradudin, Optics Letters 8, 386-388 (1983).
5.  Surface Polariton Reflection and Transmission at a Barrier, A. A. Maradudin, R. F. Wallis, and G. I. Stegeman, Solid State Commun. 46, 481-485 (1983).
6.  Surface Plasmons on Corrugated Metal Films, G. A. Farias, A. A. Maradudin, and V. Celli, Surface Science 129, 9-20 (1983).
7.  Theory of Surface Polariton Resonances and Field Enhancements in Light Scattering From Bigratings, N. E. Glass, A. A. Maradudin, and V. Celli, J. Opt. Soc. Am. 73, 1240-1248 (1983).
8.  Fresnel Relations for Surface Polaritons at Interfaces, G. I. Stegeman, N. E. Glass, A. A. Maradudin, T. P. Shen, and R. F. Wallis, Optics Letters 8, 626-628 (1983).
9.  Diffraction of Light by a Periodically Modulated Dielectric Half-Space, N. E. Glass and A. A. Maradudin, Phys. Rev. B29, 1840-1847 (1984).
10. Interface Phenomena in the Refraction of a Surface Polariton by Vertical Dielectric Barriers, Appl. Optics 23, 607-611 (1984).
11. The Optics of Surface Polaritons, G. I. Stegeman, J. de Physique, Colloque C5, supplement au n° 4, Tome 45, Avril 1984, pp. C5-233 - C5-241.
12. Refraction of a Surface Polariton by a Semi-Infinite Film on a Metal, G. I. Stegeman, A. A. Maradudin, T. P. Shen, and R. F. Wallis, Phys. Rev. B29, 6530-6539 (1984).
13. Second Harmonic Generation in Reflection From a Metallic Grating, G. A. Farias and A. A. Maradudin, Phys. Rev. B30, 3002-3015 (1984).

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